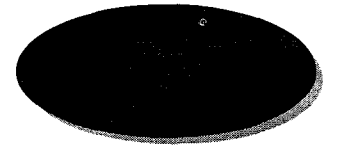


# **SPACE-FLIGHT VALIDATION OPPORTUNITIES FOR LOW-TEMPERATURE TECHNOLOGIES**

**Martin Buehler, NMP Staff Technologist, JPL  
Peter Mason, Low-Temperature Physicist, Caltech**

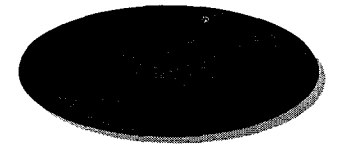
**July 12-13, 2001**

**2001 Space Cryogenics Workshop  
Milwaukee, Wisconsin**



## Introduction

- ☐ **New Millennium Program (NMP) is a flight test program providing:**
  - ☐ **Flight validation of new technologies**
  - ☐ **Reduced risk and cost to NASA's Earth and Space Science missions in the use of new technology.**
  
- ☐ **This talk will:**
  - ☐ **Describe NMP**
  - ☐ **Solicit suggestions for flight validating low-temperature technologies.**

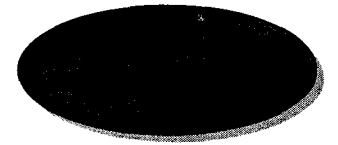


## Outline




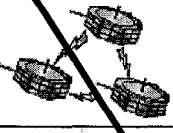



- ☐ **New Millennium Program Overview**
  - ☐ **Launch Schedule and Activity Triad**
  - ☐ **Current NMP Technologies**
  
- ☐ **Technology Selection Process**
  - ☐ **User Needs**
  - ☐ **Technology Readiness Levels (TRL)**
  - ☐ **Flight Justification**
  
- ☐ **Flight Validation**
  - ☐ **Cryogenic Technology Examples**
  - ☐ **Candidate Technologies for Flight Validation**



## ☐ NMP Overview

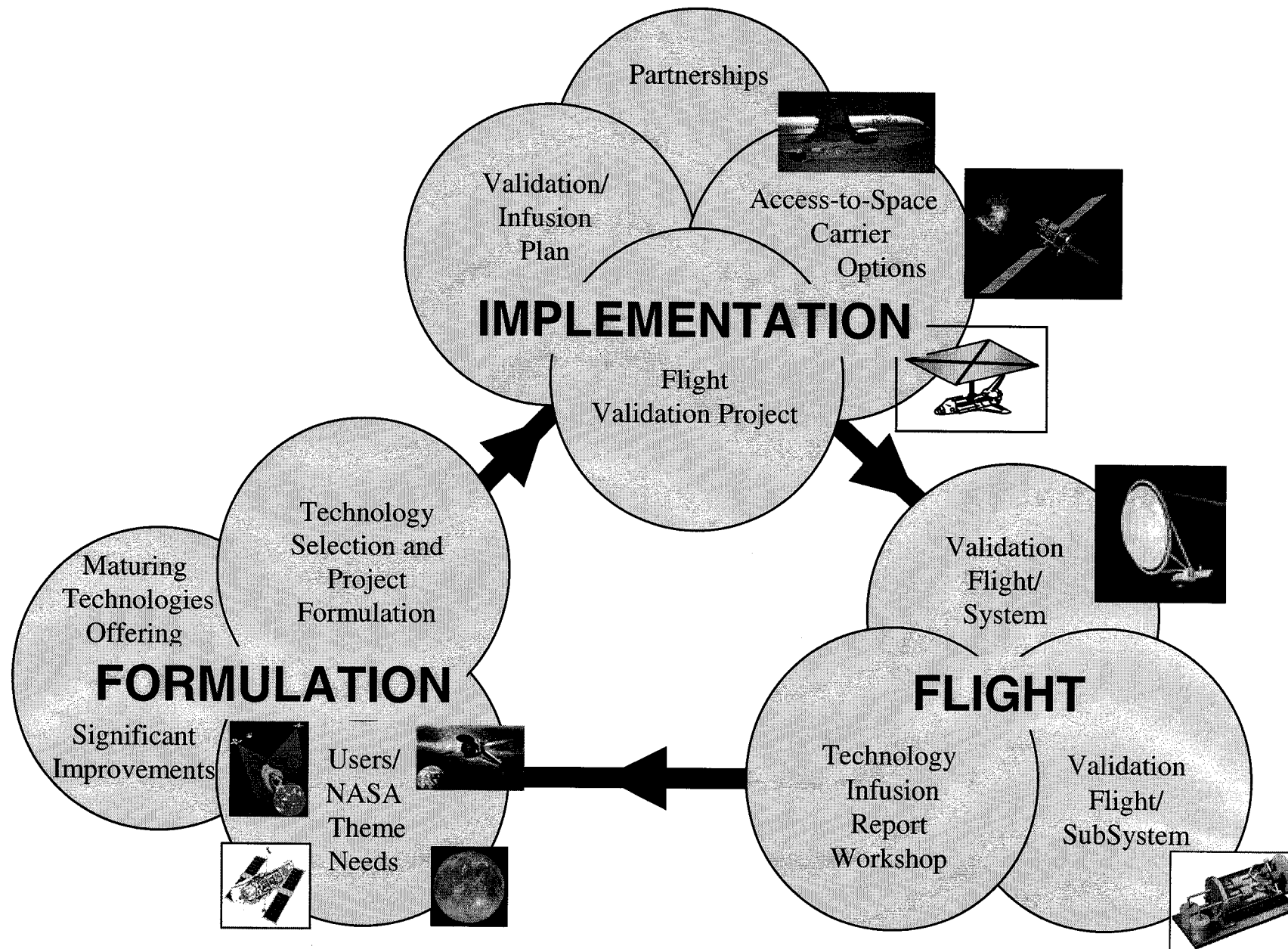


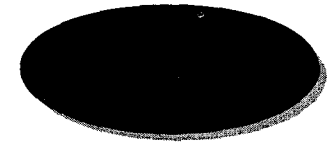
## Validation Flight Launch Schedule

Year	98	99	00	01	02	03	04	05	06
DS1	 10/98								
DS2		 01/99							
EO1	<div>One Flight Per Year</div>		 11/00						
ST5									
EO3									
ST6						<div>Two Flights Per Year</div>			
ST7									



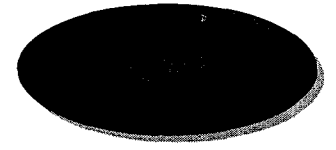
# NMP Flight Validation Activity Triad





## NMP Technologies for Flight Validation

EO3	ST5	ST6	ST7
FT Spectrometer	Satellite Constellation	SUBSYSTEM	SYSTEM
IMPLEMENTATION	IMPLEMENTATION	SELECT: ~Three tech.	SELECT: One system
2004 LAUNCH	2003 LAUNCH	2005 LAUNCH	2005 LAUNCH
Interferometer	SYSTEM	Sail/Sunshade Deploy.	DISTURB. REDUCT. SYS
Focal Plane Array	MicroSat Fabrication	LW High Volt. Solar Array	Gravitational Sensor
Mini-Cooler	Research Quality S/C	Deployable Inflat. Booms	MicroNewton Thruster
RH-A/D Converter	Constellation Operation	Membrane Optics Deploy.	SOLAR SAILS
RH-Vector Processor	SUBSYSTEM	Ultra-Low Power Avionics	Sail Subsystem
Active Pixel Sensor	Micro-Thruster	Optical Communication	Attitude Control
Star Tracker	X-Band Transponder	On-Board Data Processing	Diagnostic Instrument.
LW-Optics & Struct.	Ultra-Low Power Logic	Dilution Cryocooler	Navigat. & Traject. Tools
Power PC	Flexible Harness		AERO-ENTRY/MANEUVER
Stacked Memory	Emmisivity Tech.		Aeroshell Design/Fab
Ultra-Low Power Logic	Constellat. Transceiver		Aerodynamic Design
Radiation Shielding	SatTrack Constel. Tools		Guidance Algorithms
			Advanced Instrumentat.
			AUTONOMY
			On-Board Sci. Process.
			Sys.-Level Auto. Software
			Sys.-Level Auto. Enabler
			Adv. Autonomous Enabler
			Hardware Concepts

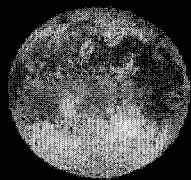


## ☐ Technology Selection Process





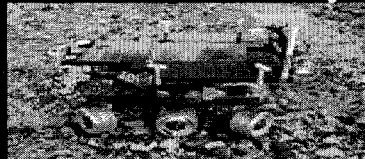
# Science Theme Technology Validation Needs



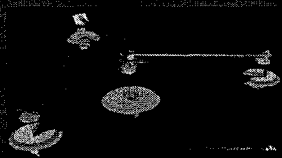
**Aeroassist Ballutes**



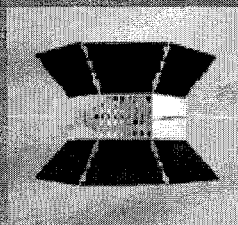
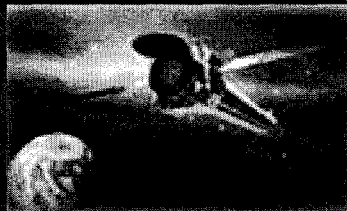
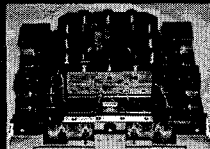
**Robotic Assembly**



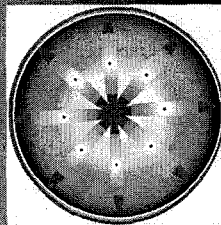
**Tethers**



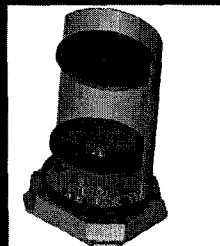
**Drag Free  
Inertial Sensors**



**Microspacecraft**



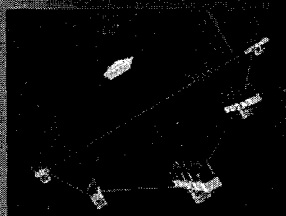
**Solar Sail**



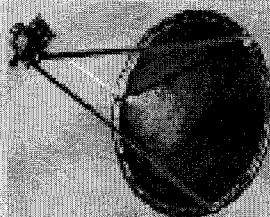
**Optical Communication**



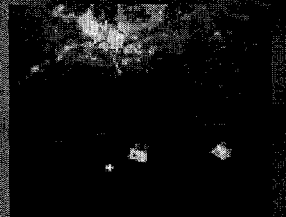
**Advanced  
Instruments**



**Autonomy &  
On-board Processing**

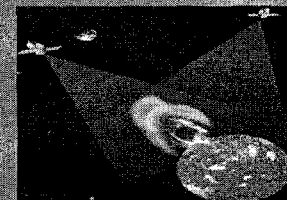


**Light Weight  
Deployable  
Precision  
Structure**



**Precision  
Formation Flying**

## Sun Earth Connection



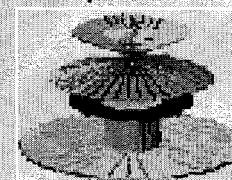
**Data Synthesis**



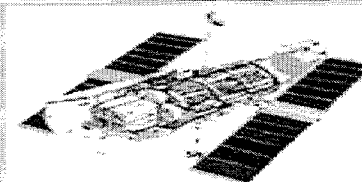
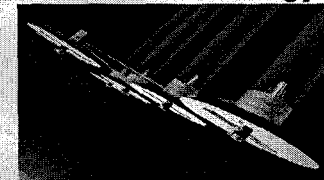
**Constellation Operation**



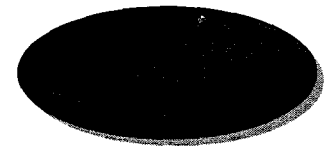
**Gossamer  
Optics**



**Thermal Control  
Precision Metrology**



## Astronomical Search for Origins



## NASA Technology Readiness Levels

**TRL 9 Actual system flight proven through successful mission operations.**

**TRL 8 Flight System completed and qualified through test and demonstration.**

**TRL 7 System prototype demonstrated in a space environment.**

**TRL 6 System prototype demonstrated in a relevant environment.**

**TRL 5 Component and/or breadboard validated in relevant environment.**

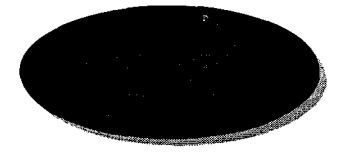
**TRL 4 Component and/or breadboard validated in laboratory environment.**

**TRL 3 Critical function or characteristic demonstrated (proof-of-concept).**

**TRL 2 Technology concept and/or application formulated.**

**TRL 1 Basic principles observed and reported.**

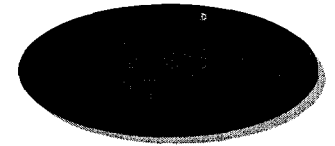
NMP flight validates technologies that have matured to TRL 4.



## Flight Validation Justification Factors

FACTORS	EFFECTS	EXAMPLES
1. <b>Persistent Effects</b> are steady space/planetary environments acting on the technology.	Zero Gravity, Radiation Effects, Temperature Cycling.	Large, light-weight deployable structures need zero g flight validation because accurate ground tests are impossible.
2. <b>Transient Effects</b> are impulse space/planetary environments acting on technology.	Cosmic Rays, Temperature Spike, Dust Devils, Vibration, Coronal Mass Ejection.	System level faults, such as cosmic-ray induced single-event upsets in integrated circuits. Validation flight needed to demonstrate performance of fault management software and planning agents.
3. <b>External Interactions</b> are environments used by the technology to accomplish something.	Planetary Atmospheres, Solar Wind, Magnetic Fields.	Aeroassist technologies using planetary atmospheres and solar sails using solar wind for propulsion. Both require flight validation to build an experience base and to determine the performance envelope and safe operating zones.
4. <b>Reliability Hazards</b> are space/planetary environments that degrade performance.	Micrometeorite, Dust Accumulation, Atomic Oxygen, Radiation Effects.	Micrometeorite, orbital debris, dust accumulation, atomic oxygen, and radiation effects are difficult to predict and simulate.

Justification based on space environmental effects where ground tests are difficult or impossible.



## NMP Flight Validation Selection Target

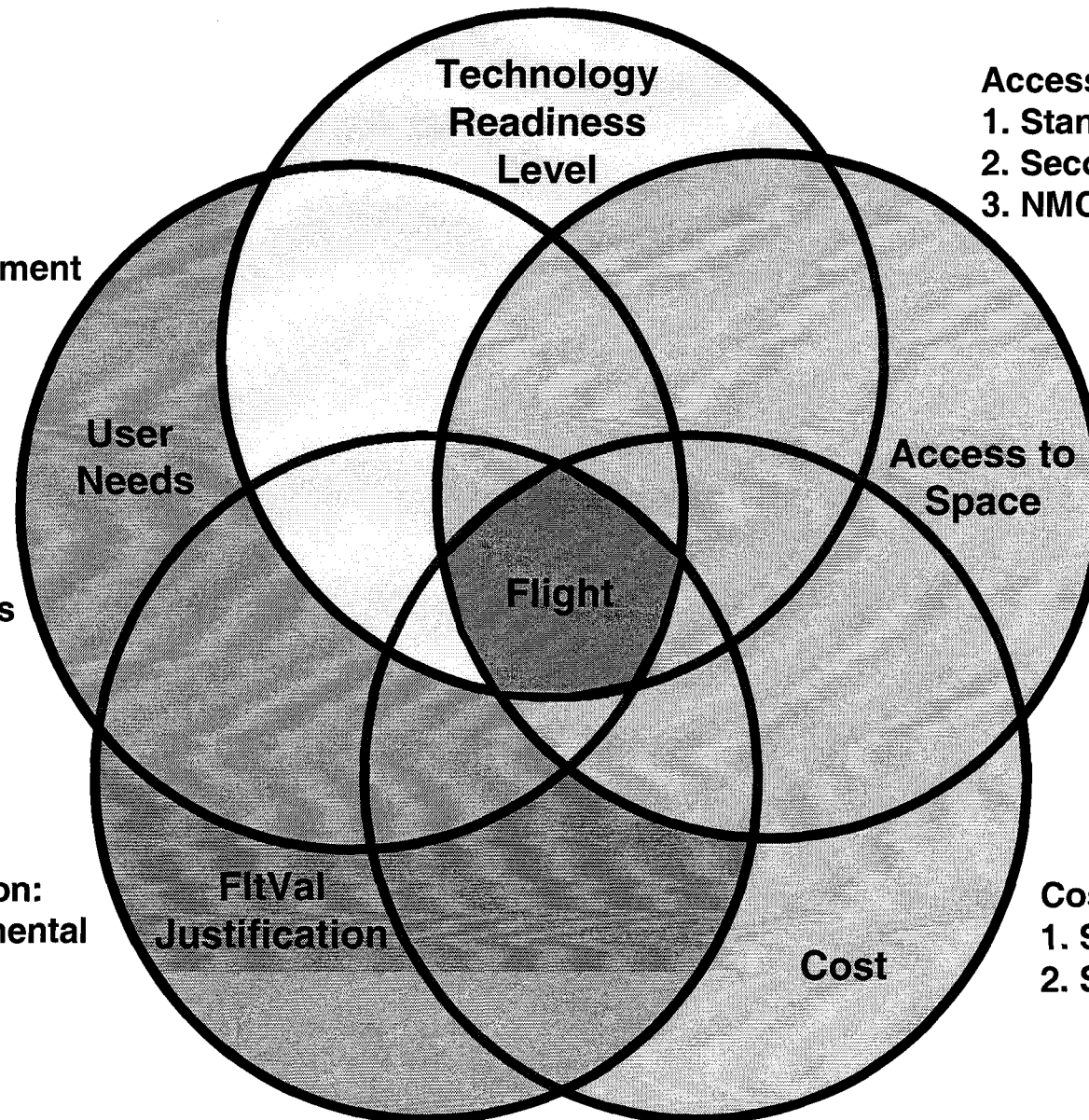
### TRL:

1. Principle
2. Concept
3. Proof
4. Lab Demo
5. Relevant Environment
6. System Demo
7. Flight
8. Demo
9. Operation

### User Needs

1. NASA Theme
2. NASA Enterprises

FltVal Justification:  
-Space Environmental  
Effects



Technology  
Readiness  
Level

### Access to Space:

1. Standalone Spacecraft
2. Secondary Payload
3. NMCarrrier

Access to  
Space

Flight

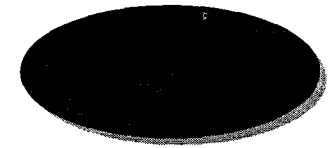
Cost

### Cost:

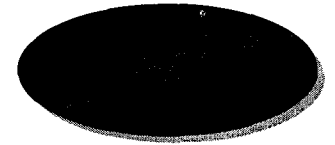
1. System: \$50M
2. Subsystem: \$5M

FltVal  
Justification

User  
Needs



## ☐ Flight Validation



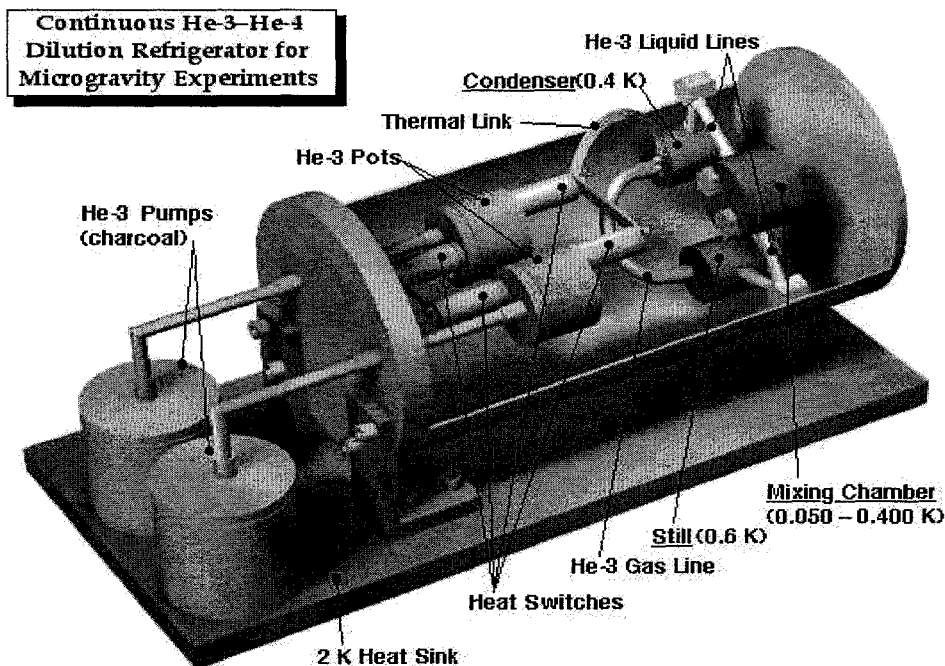
## NMP System/Subsystem Flight Opportunities

ATTRIBUTE	SYSTEM	SUBSYSTEM
Definition	Several higher-TRL technologies tested in a system context.	Lower-TRL new technologies tested individually.
Normal Project Class	Flight: Shared with partner(s)	Flight: Shared with partner(s)
	Cost: \$50M	Cost: \$25M supporting several new technologies
Occasional Project Class	Flight: Stand-alone	Flight: Hosted by the NASA technology carrier
	Cost: \$100-\$150M	Cost: \$25M supporting several new technologies.
Launch	Annual	Annual

NMP has two approaches to flight validation.



## Subsystem-Level Validation: Dilution Cryocoolers



### • **Technology Description:**

Cryocoolers enable the use of low temperature detectors that measure photons with energies ranging between X-rays through IR. The dilution cryocooler uses liquid helium to achieve temperatures between 50 and 300 mK. Cooling occurs without the use of stored cryogenics, with no moving parts, no vibration and no magnetic fields. The size is 25 cm dia. X 40 cm long. The mass is < 2 kg and requires 25 mW peak electrical power and a 2 K heat sink with a < 3 mW capability.

### • **Flight Validation Justification:**

- Dilution cryocoolers are difficult or impossible to test on the ground due to gravity sensitive of the He-3 and He-4 and require flight validation to demonstrate their performance in a space.

### • **Customers:**

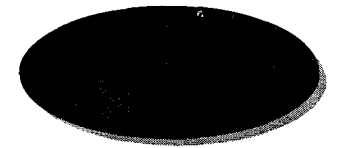
- Missions with X-ray or IR requirements.
- FIRST, Constellation-X, SOFIA, Plank (ESA), SPECS, HIRLODLS; NGST; SUVO

### • **Validation Measurements:**

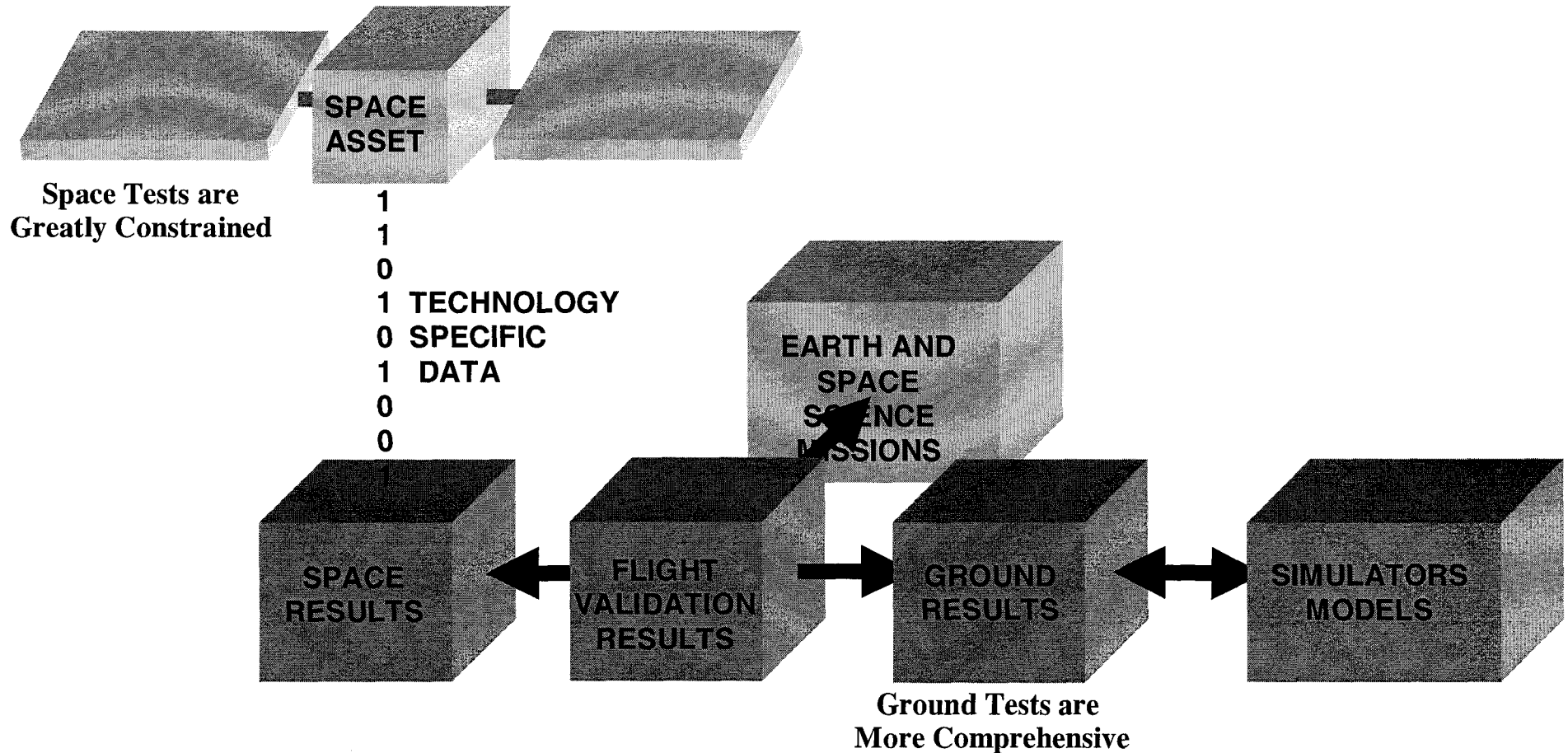
- Measure the temperature of the dilution cryocooler in space to determine its stability and dynamic behavior.
- Measure the power required to reach lowest temperatures.

### • **Technology Status:**

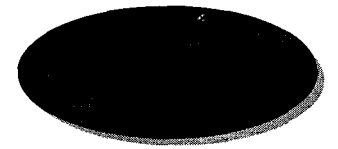
- A single-cycle prototype with necessary porous material for controlling the liquid has been demonstrated on the ground. It is being modified to operate continuously. The technology is expected to reach TRL 4 by FY02.



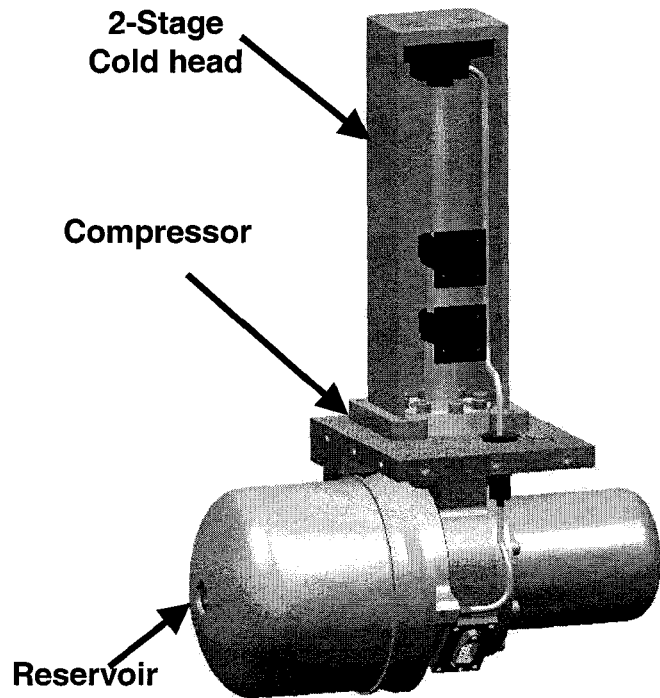
## Flight Validation Elements







## System-Level Validation: Miniaturized Pulse-Tube Cryocooler



Two-Stage Cryocooler

### • **Technology Description:**

The two-stage pulse-tube cooler will provide a stable 55K (2-W load), 90K, and 120K for FPA cooling and for zonal cooling of the instrument. The cooler provides second-stage cooling at ~140 K, 7-W load, allowing the interferometer to be cooled for lower background noise operation. Mass is 17, kg, power is 170 W, and rejection temperature is 300 K.

### • **Flight Validation Justification:**

- The space steady state and dynamic temperature response is difficult to predict based on ground tests.
- The space cooler vibration performance is difficult to predict based on ground tests.

### • **Customers:**

- Enabling technology for NOAA, ONR, FAA, and NASA's Earth and Science Enterprises.

### • **Validation Measurements:**

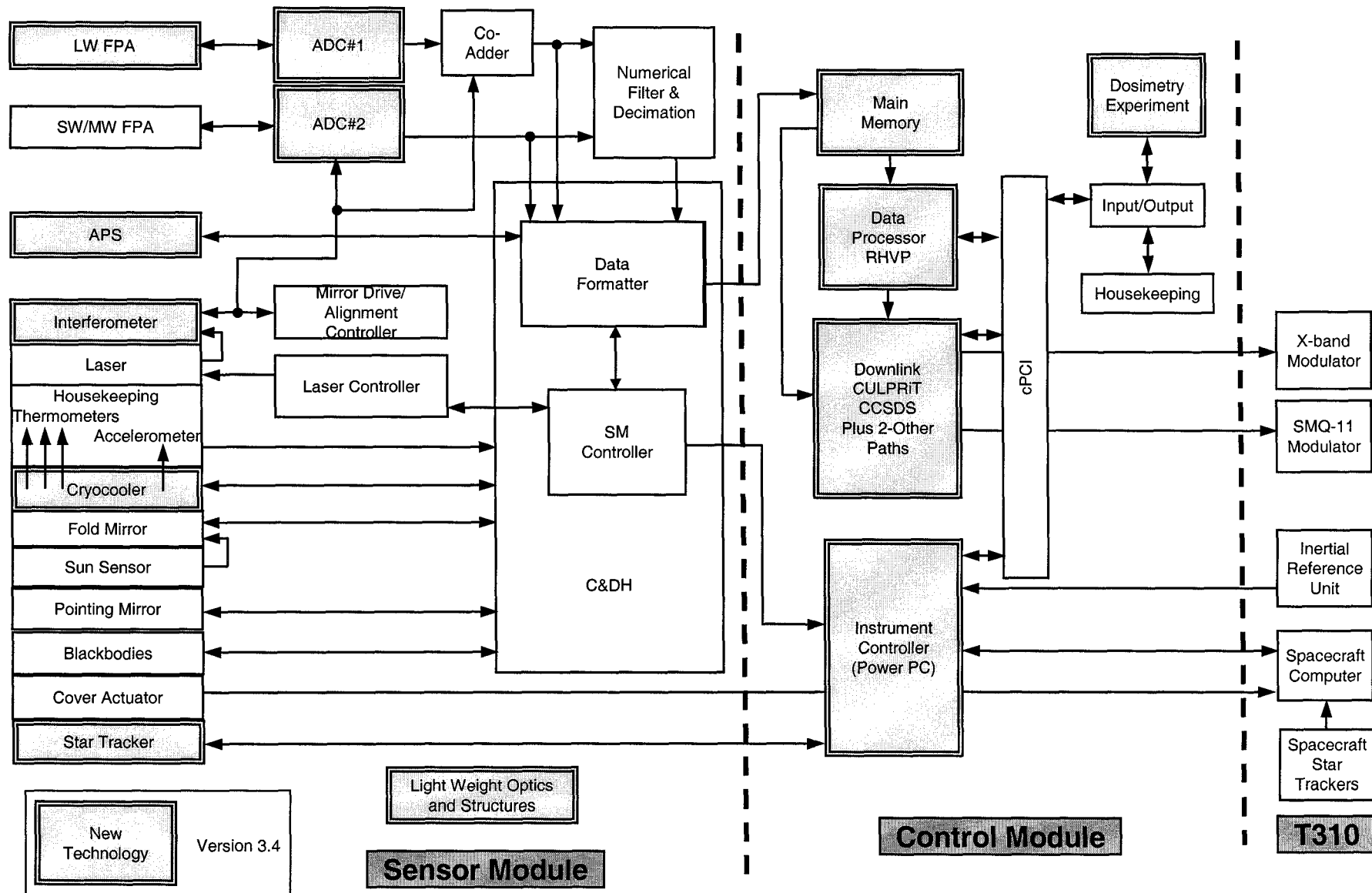
- Measure the input power and cooler temperature sensors to determine the power efficiency
- Measure the cooler temperature sensor to determine the temperature stability
- Measure the cooler accelerometer to gather vibrational and perhaps mechanical reliability statistics.

### • **Technology Status:**

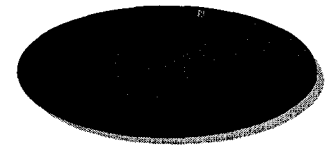
Bench model of the cooler currently under test has demonstrated a factor of four improvement in mass per unit power over coolers of similar capacity (3.9 kg for GIFTS versus 11 kg for AIRS/TES). The technology is expected to reach TRL 4 by FY02.



# System-Level Technology Validation: EO3 GIFTS



Validating technology at the system-level is challenging because the technology is embedded in the system and so requires extensive operations and instrumentation planning.



## **NMP Events**

### **❑ TECHNOLOGY INFUSION:**

- **DS1 Workshop: January 2000**
- **DS1 CDRM: January 2001**
- **EO1 Workshop: August 2001**
- **DS2 Report: August 2001**

### **❑ FLIGHT:**

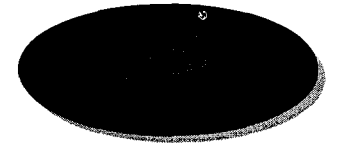
- **ST5 Launch: 2003**
- **EO3 Launch 2004**

### **❑ TECHNOLOGY SELECTION:**

- **ST6 Selection August 2001**
- **ST7 Selection December 2001**

### **❑ TECHNOLOGY FORMULATION:**

- **ST8 Subsystem Workshop January 2002**



## **Low-Temperature Technologies**

### ☐ **CRYOCOOLERS**

- **Cooling Mechanisms**
- **Reliability**

### ☐ **HEAT TRANSFER AND COMPONENTS**

- **Heat Exchangers**
- **Fluid Flow Valves**

### ☐ **SPACE TRANSPORTATION**

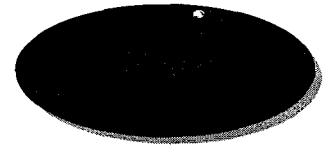
- **Propellants and Storage**
- **Liquid Measures**

### ☐ **FACILITIES**

- **Test Capabilities**
- **Simulators and Modeling**

### ☐ **OTHER**

- **Microelectronic Cooling**
- **Contamination**



## **Flight Validation Assessment**

### **☐ Identify Needs:**

- **Identify Mission application**
- **Determine if a NASA Theme(s) is interested**

### **☐ Determine the Viability of the Technology:**

- **Determine if the technology is ready (TRL)**
- **Decide on the Flight Justification**
- **Determine if the Cost is reasonable**
- **Identify the Access-to-Space options**

### **☐ Advertise:**

- **Inform the NASA Theme(s) of the technology**
- **Participate in an NMP Workshop**
- **Respond to an NMP TA (Technology Announcement)**